

Dark Matter Searches with Germanium Detectors with sub-keV Sensitivities

- Overview (Collaboration ; Program ; Laboratory)
- Calibration & Energy definitions
- Event selection and efficiencies
- Dark Matter analysis
- Status & plans



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On Behalf of TEXONO Collaboration, Academia Sinica

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TEXONO + CDEX Collaboration

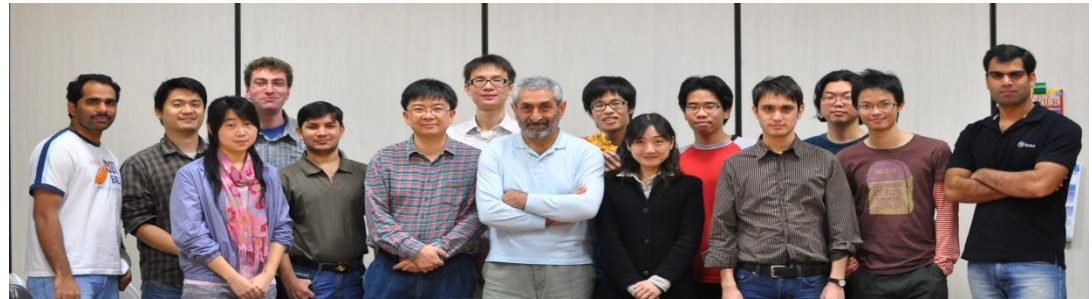


➤ TEXONO: *Kuo-Sheng (KS) Reactor Laboratory*

Taiwan (AS, INER, KSNPS, NTHU)

+ **Turkey** (METU)

+ **India** (BHU)



➤ CDEX: *China Jin-Ping Underground Laboratory (CJPL)*

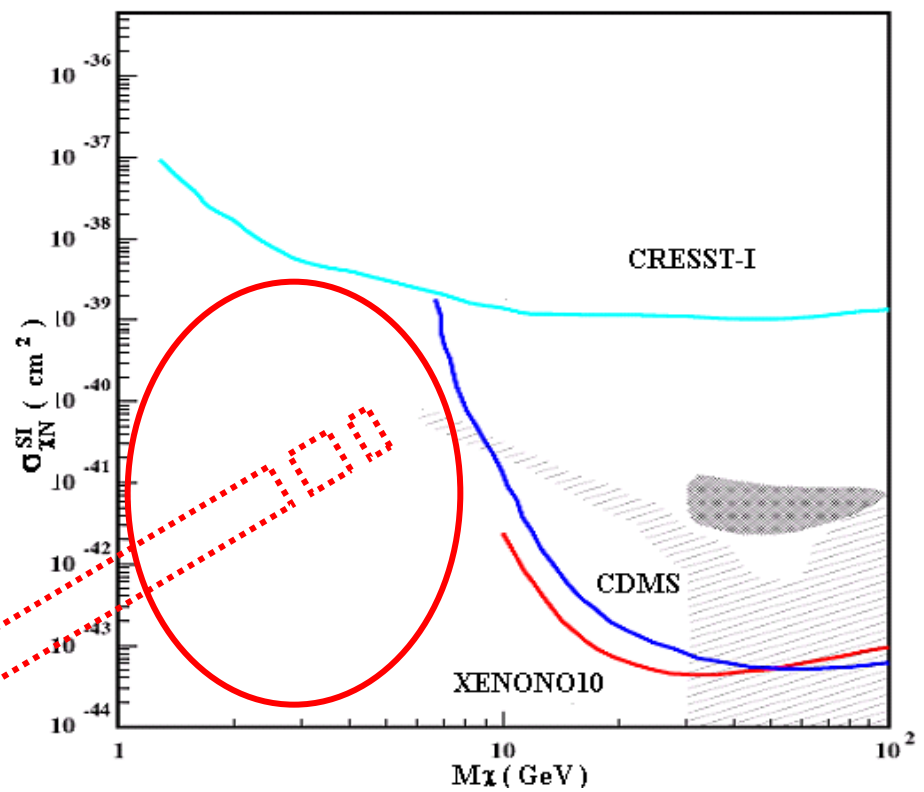
China (THU, SUC, IHEP, CIAE, NKU,, EDHC)

➤ Present Goals: Develop $O[100 \text{ eV threshold} \oplus 1 \text{ kg mass} \oplus 1 \text{ cpkcd detector}]$
for neutrino physics and dark matter searches

Sensitivity Plot for *WIMP* direct search

$$\chi N \rightarrow \chi N$$

- A^2 dependence (spin-independent)

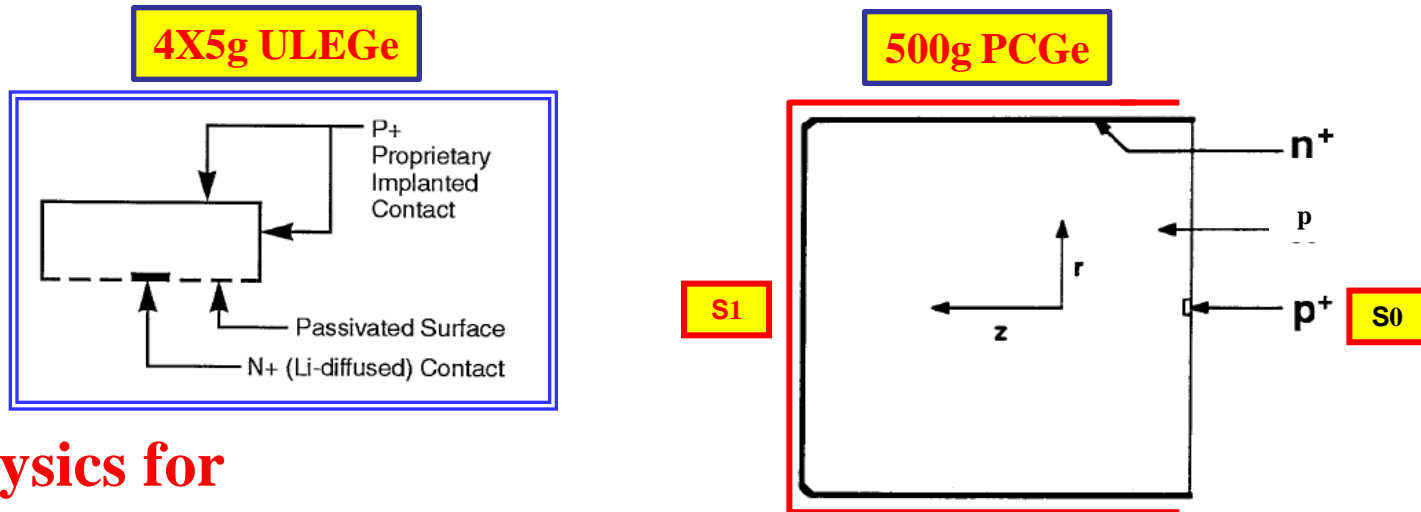


Low (<10 GeV) WIMP Mass / Sub-keV Recoil Energy :

- Not favored by the most-explored specific models on galactic-bound SUSY-neutralinos as CDM ; *still* allowed by generic SUSY
- Various gravitational effects favor lower recoil energy \Rightarrow *Solar-system bound* WIMPs ; *Dark Disk* etc.
- Other candidates favoring low recoils exist \Rightarrow non-pointlike SUSY *Q-balls* , MSSM with MeV mass ; SM+scalar ; axion-like models ; Mirror dark matter ; Asymmetric dark matter ; WIMPless.
- Less explored experimentally

Sub-keV HPGe Detectors

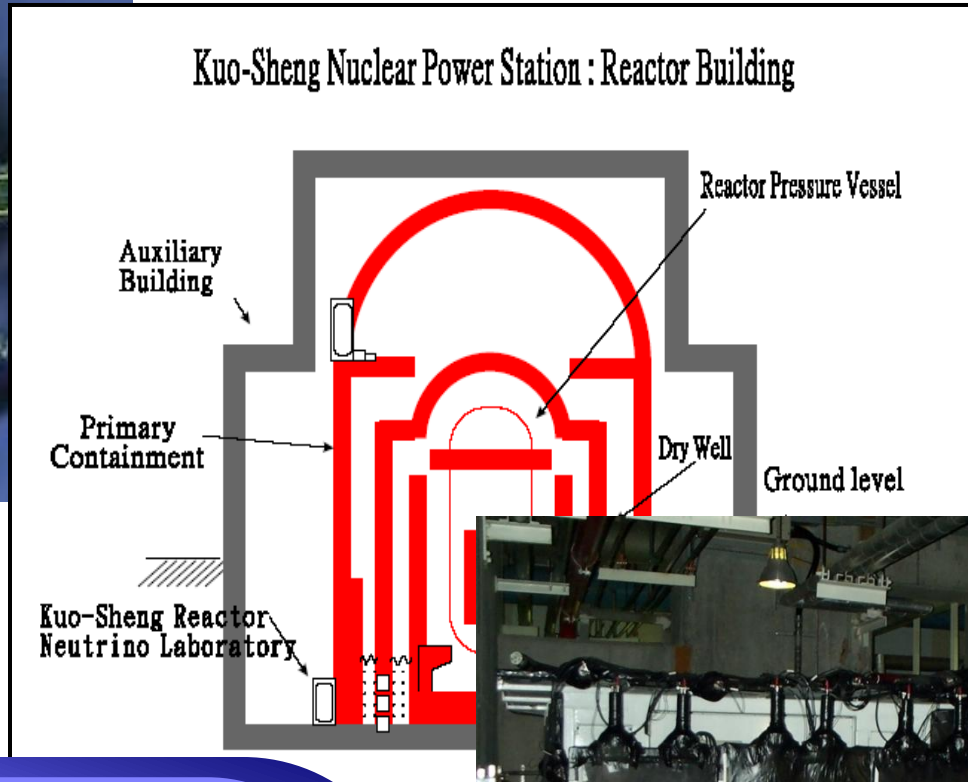
- Sub-keV Ge Prototypes built and being studied : (5-900) g



- Physics for

- ⊙ νN coherent scattering
- ⊙ Low-mass WIMP searches
- ⊙ Improve sensitivities on μ_ν
- ⊙ Implications on reactor operation monitoring
- ⊙ Open new detection channel & detector technology windows for surprises

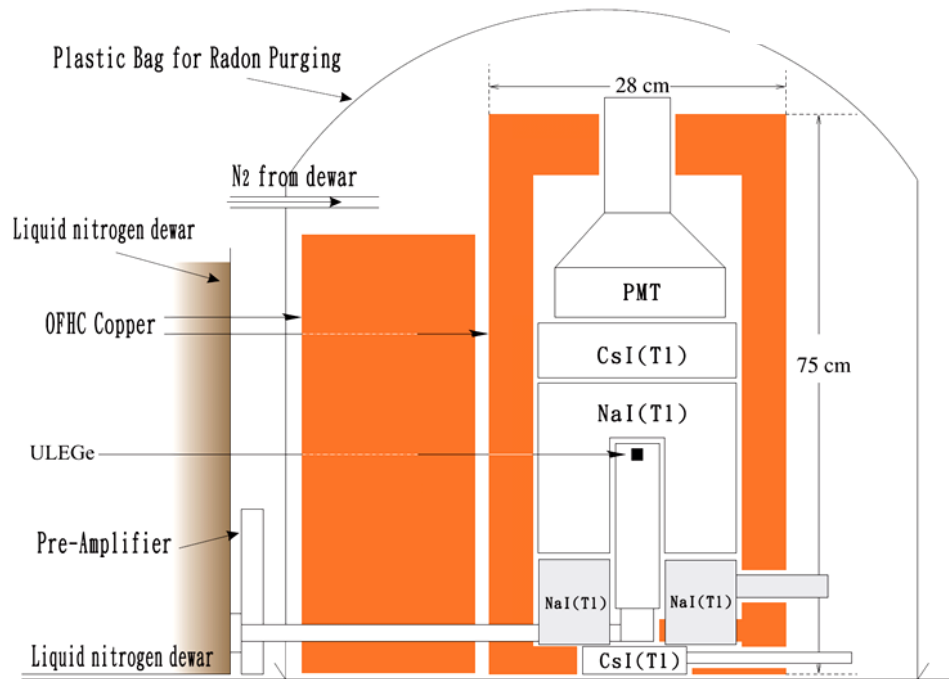
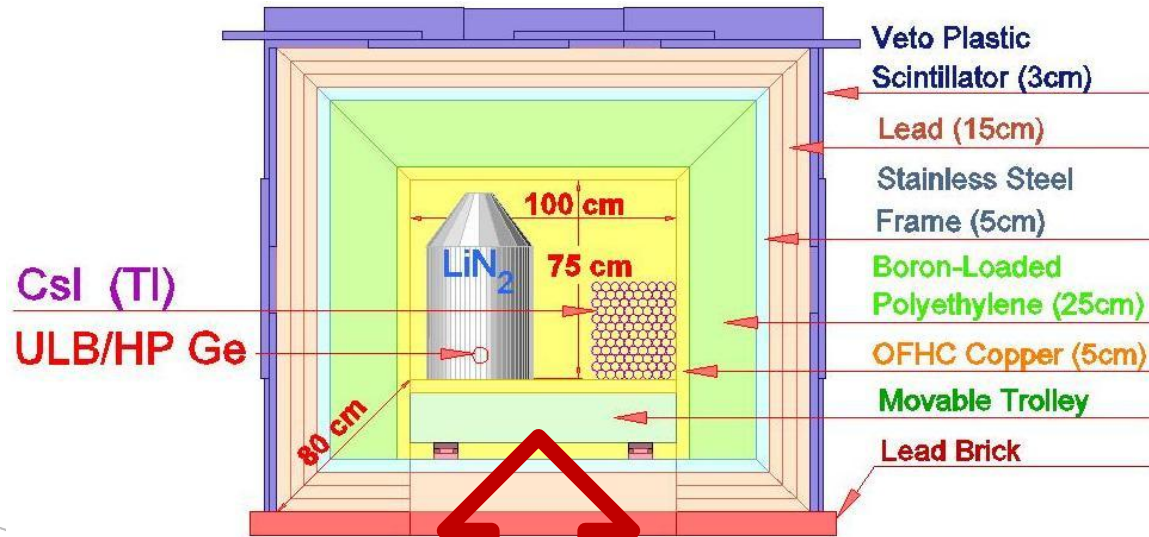
Kuo-Sheng Reactor Neutrino Laboratory :



28 m from core#1 @ 2.9 GW
Shallow site : ~30 m..w..e. overburden
~10 m below ground level

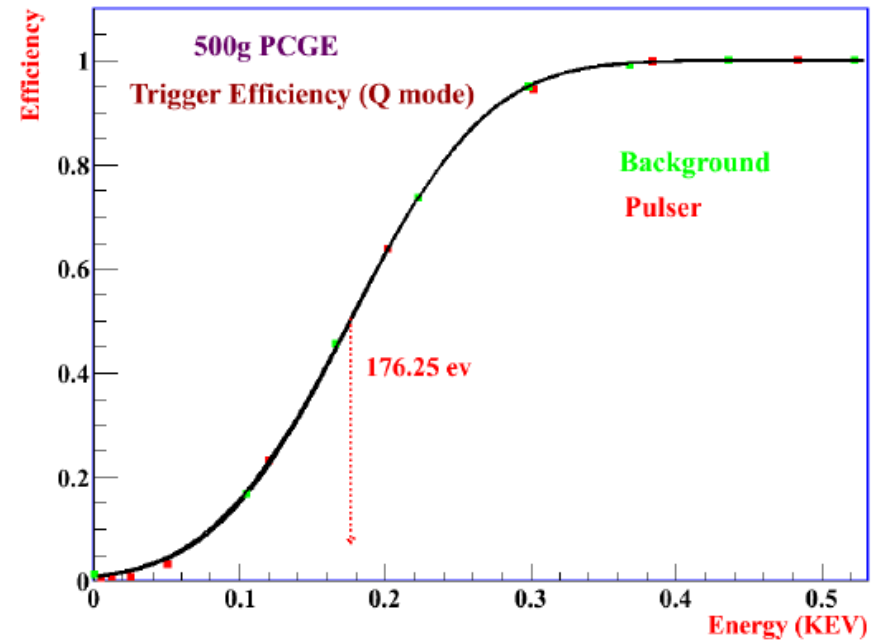
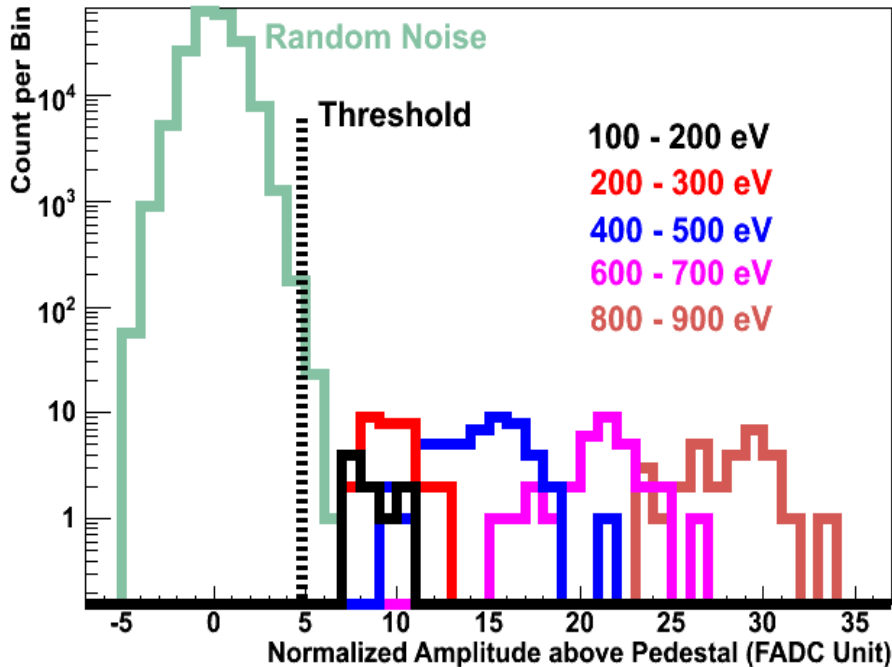
Analysis : Event Selection *CRV* , *ACV* Cut

- compact all-solid design : *ULEGe* (4 X 5 g ; 500g) surrounded by active *NaI/CsI* anti-Compton detectors, plus passive shielding & cosmic veto



- Candidate events : survive Anti-Compton (*ACV*) and Cosmic-Ray (*CRV*) vetos
- Efficiency evaluated by Random trigger events.

Evaluation of Trigger Efficiency

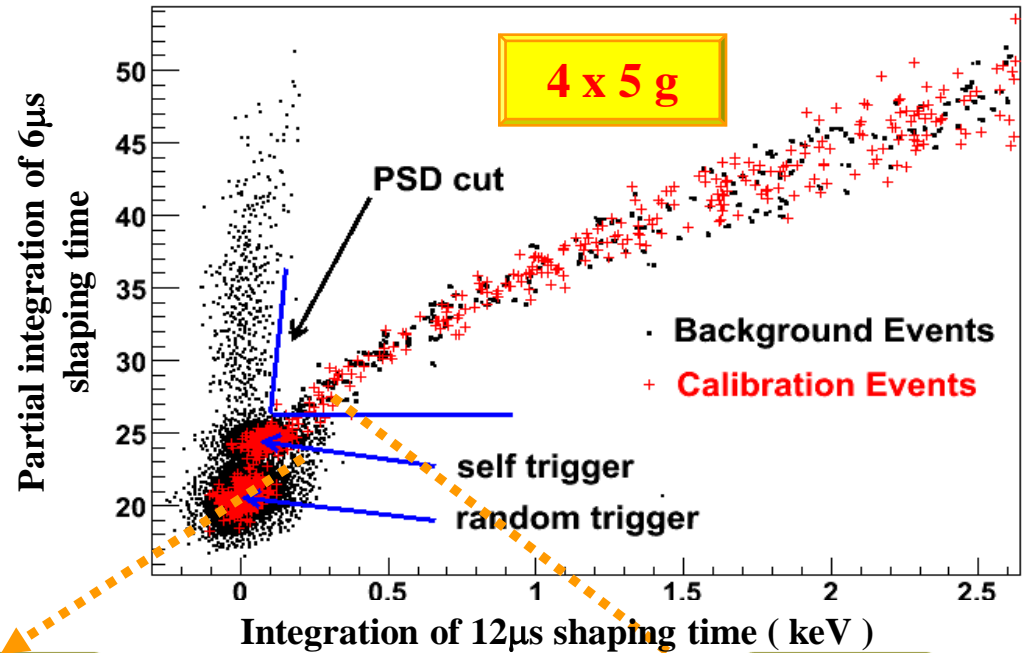


- Max. amplitude of physics events → good margins above threshold
- Efficiency Evaluation : from (*mean* , *RMS*) of Max. amplitude distribution
- Evaluation from pulser generator also perform the same behavior

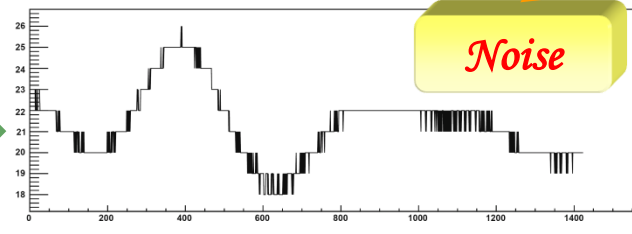
PSD Selection to Suppress Electronic Noise

– Correlate different gains & shaping times

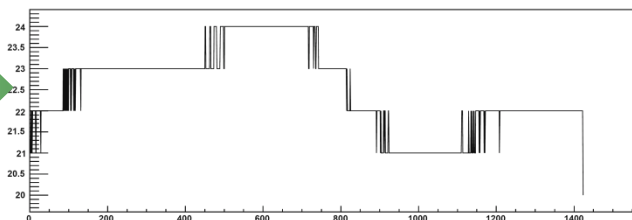
- Sampling of Specific Range for $6\ \mu\text{s}$ shaping time i.e. look for pulse fluctuations at specific and known times
- Energy as defined by integration



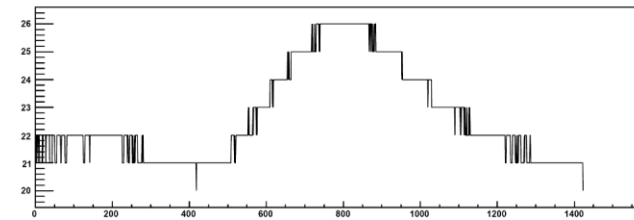
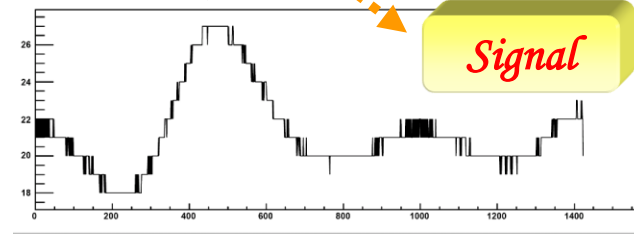
$6\ \mu\text{s}$



$12\ \mu\text{s}$



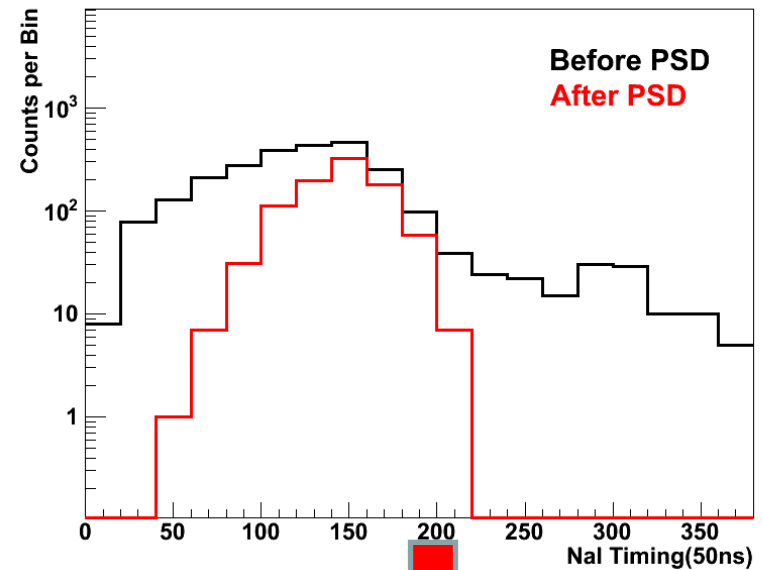
Integration of $12\ \mu\text{s}$ shaping time (keV)



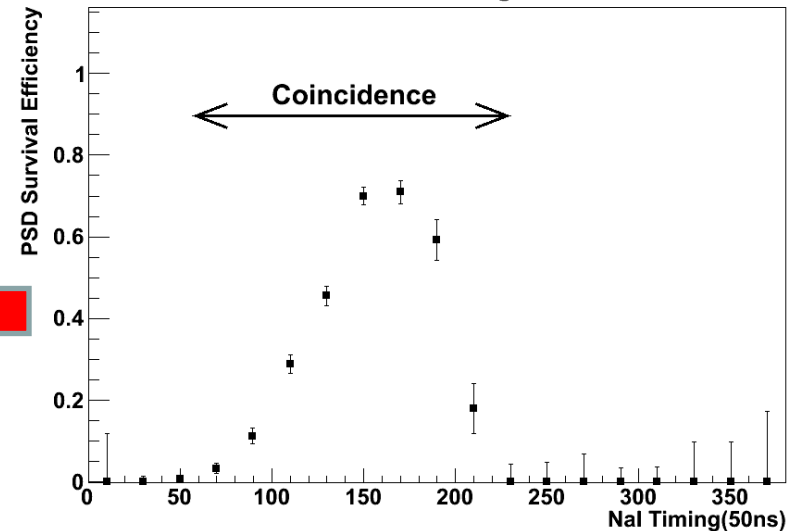
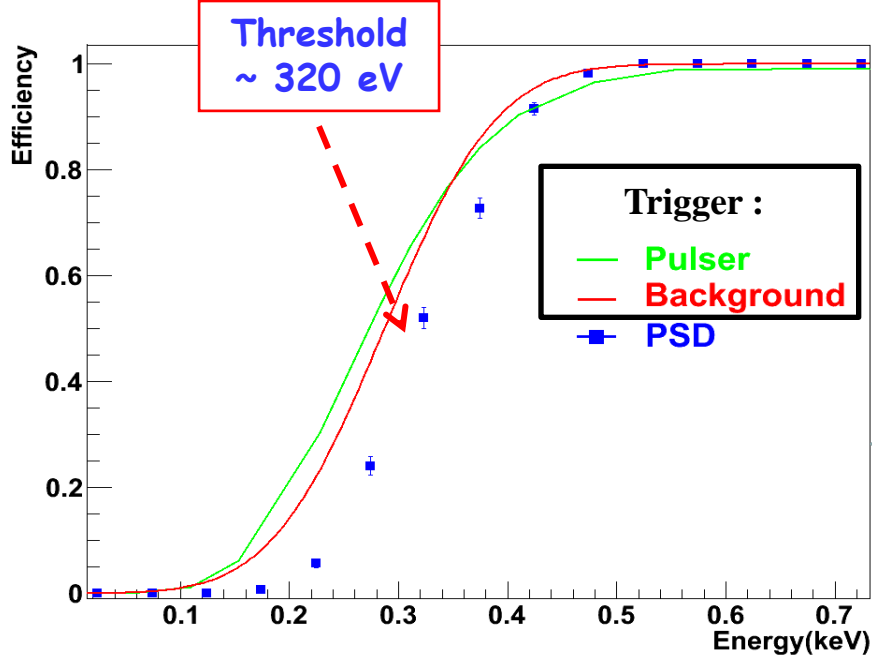
PSD Selection Efficiency

- Clean physics event samples selected by ACV tag at a known interval of Ge-AC timing

$$f = \frac{(\epsilon_{\text{PSD}} * P + f_N * N)}{P + N}$$

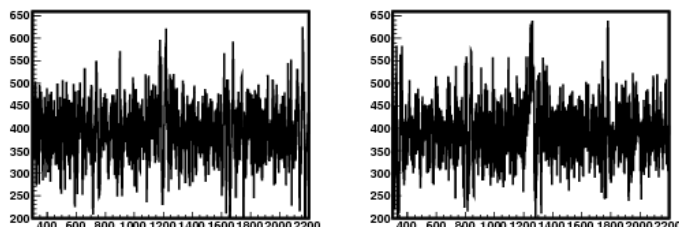


ACV tag Events at 200-400eV

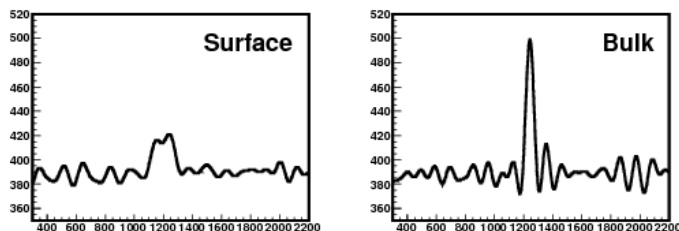


Discrimination on the Surface and Bulk events (> 2 keV)

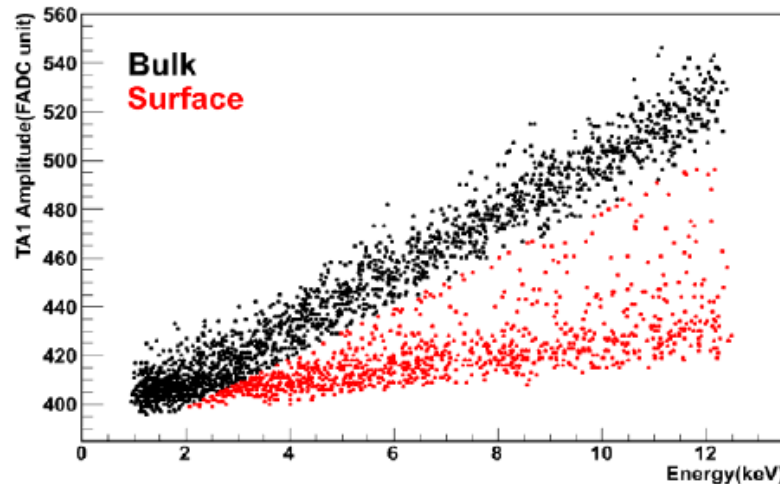
Raw pulse



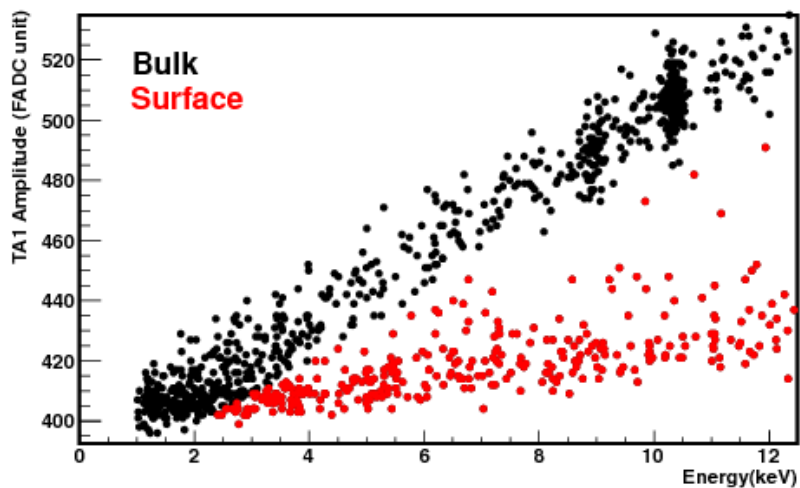
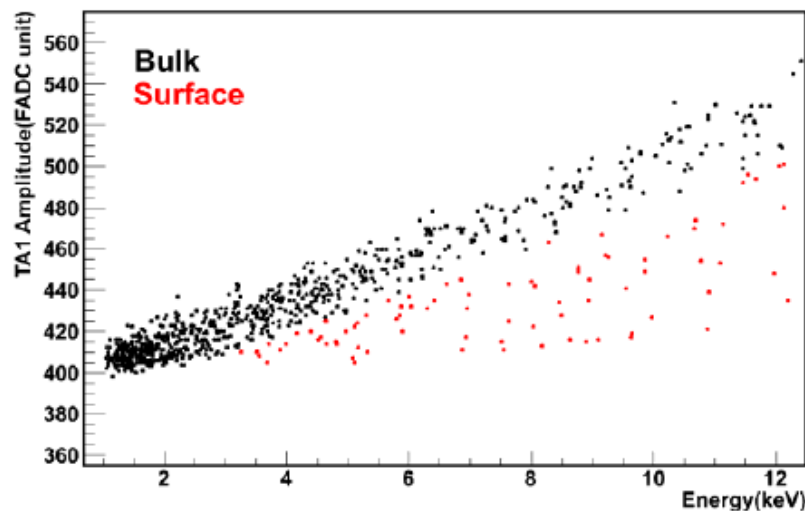
smoothed



γ -rich background (CRV+ACT)

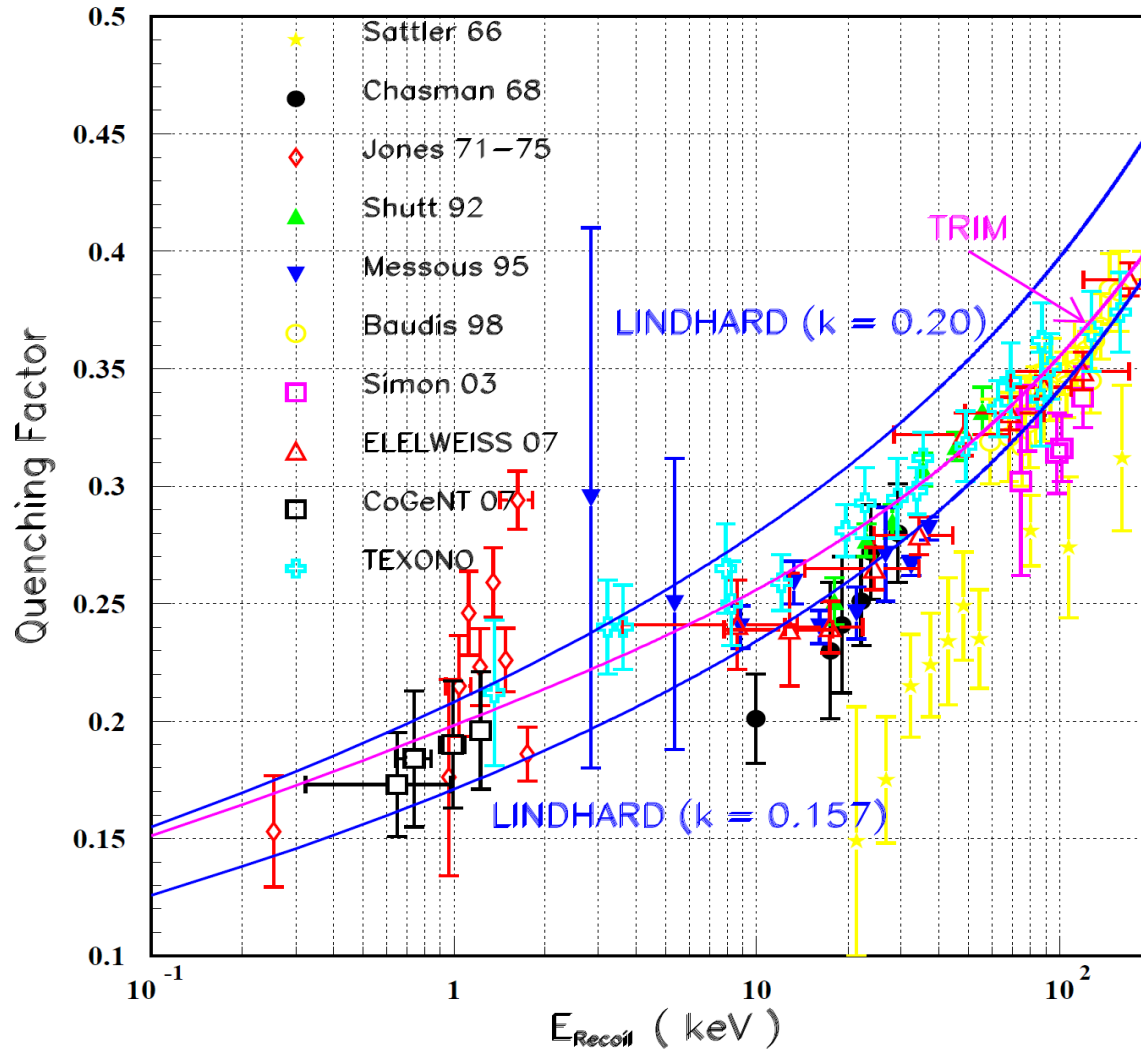


n-rich background (CRT+ACV)



Signal candidates (CRV+ACV)

Quenching Factor [Ionization Yield \Rightarrow Recoil Energy]



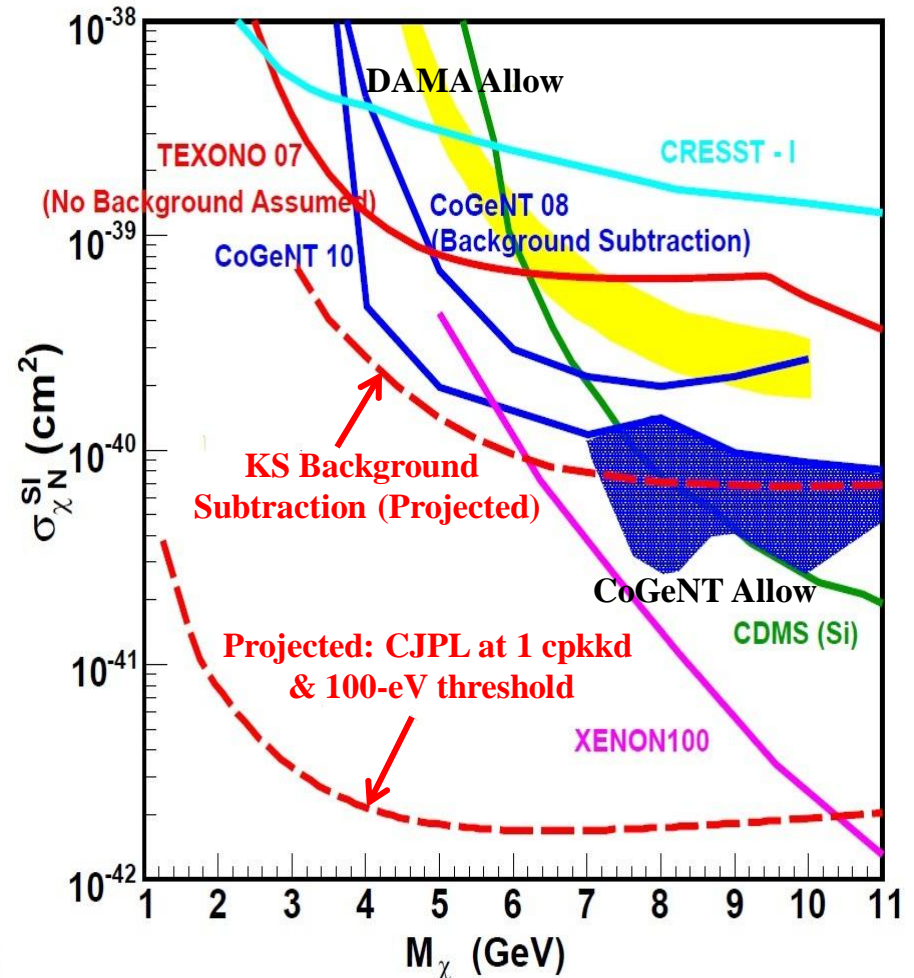
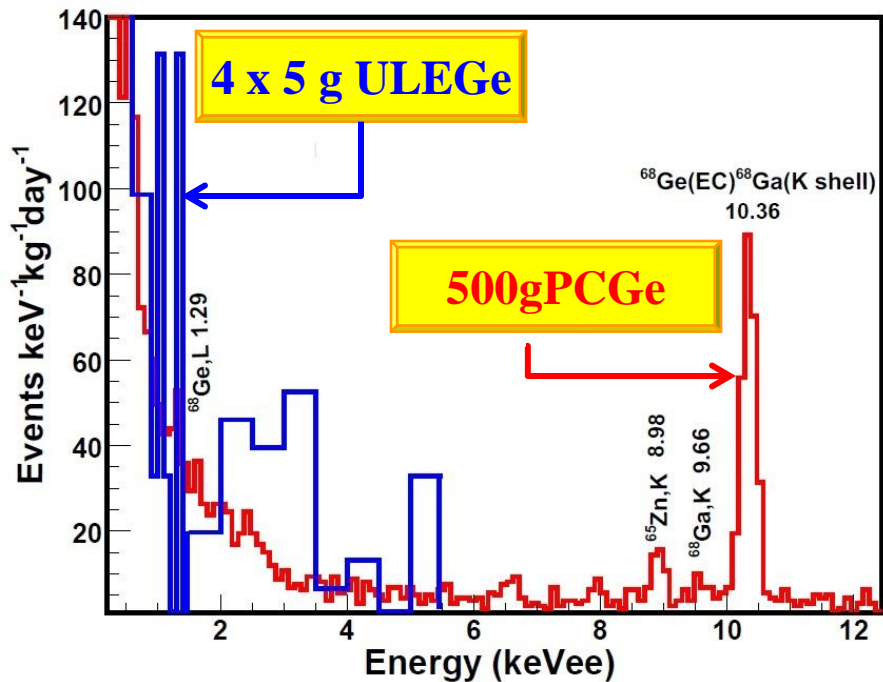
➤ TRIM (better fits to available data over extended energy)

WIMP searches

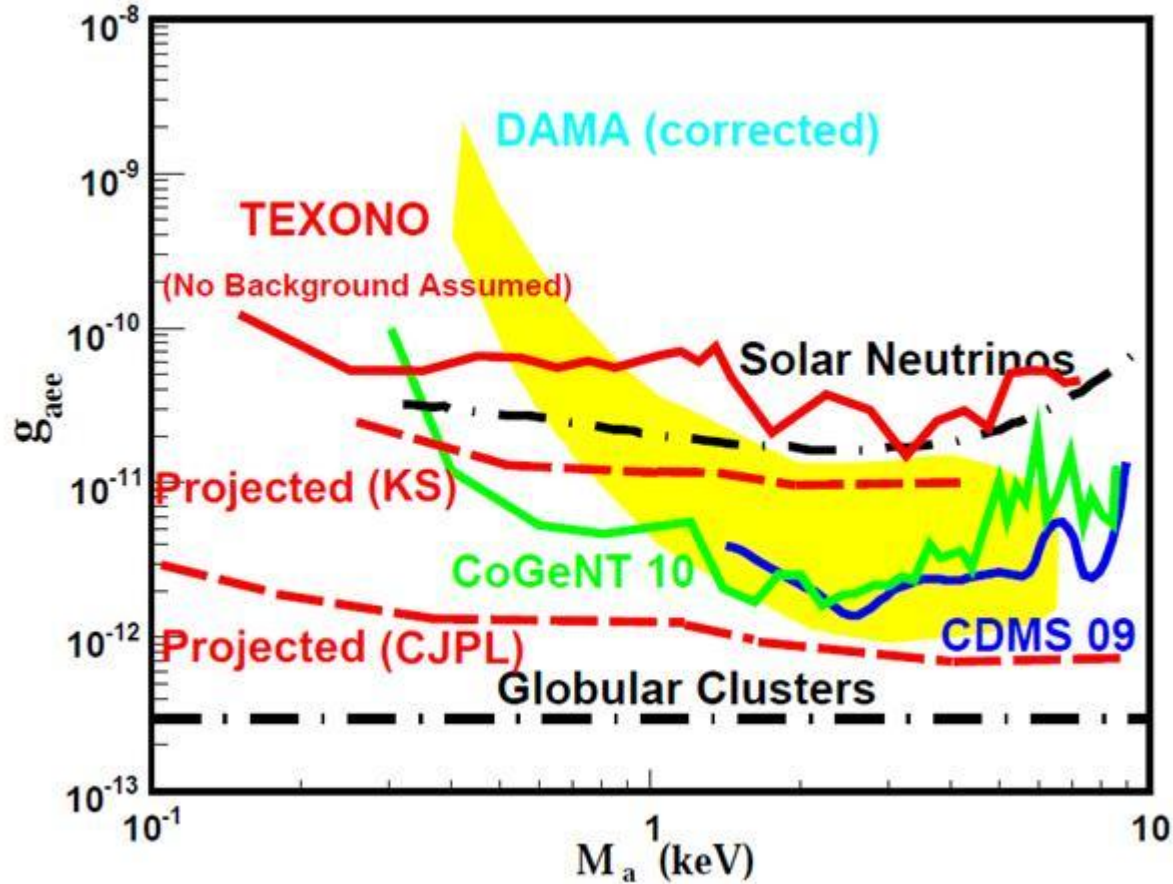
➤ Background Understanding & Subtraction

- generic γ -like source
- residues of cosmic-induced
- surface events at low energy

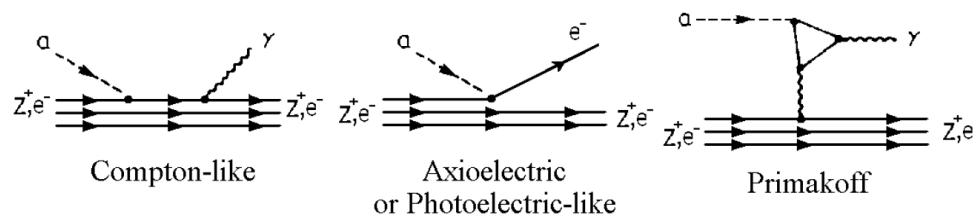
➤ Threshold reduction by software



Pseudoscalar Candidates (*axionlike*)

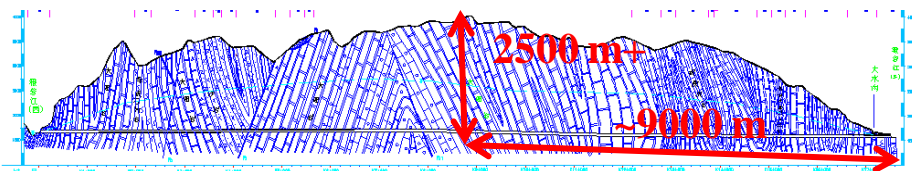
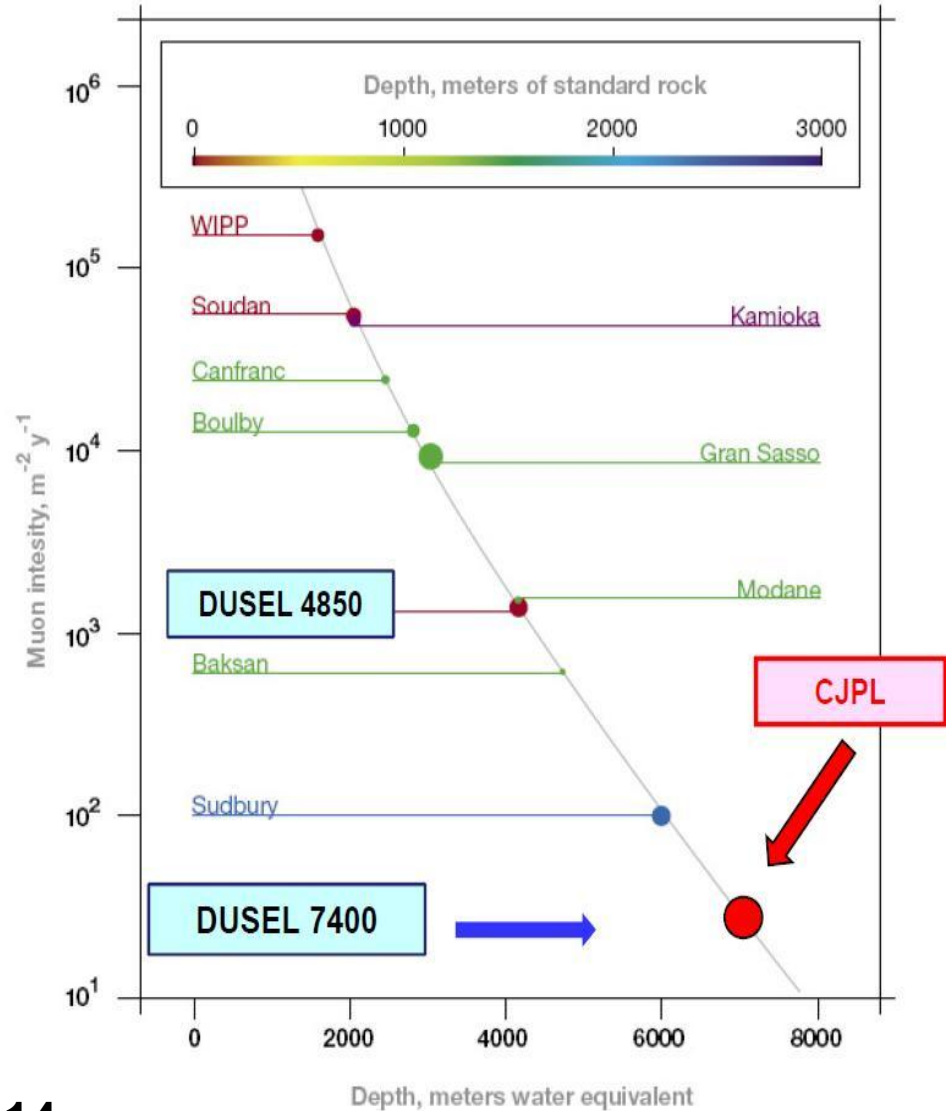
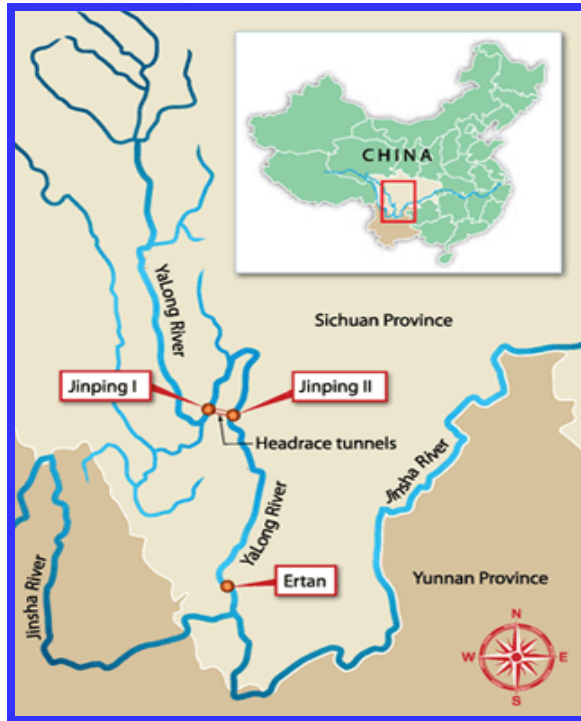


$$R \simeq \frac{1.2 \times 10^{19}}{A} g_{aee}^2 \left(\frac{m_a}{\text{keV}} \right) \left(\frac{\sigma_{photo}}{\text{bn}} \right) \text{kg}^{-1} \text{day}^{-1} \quad \text{Formula: Pospelov et al. PRD 78, 115012 (2008)}$$



China Jin-Ping Underground Lab (CJPL): WIMP searches

- ① 2500 m+ rock overburden
- ① Drive-in access in the Tunnel



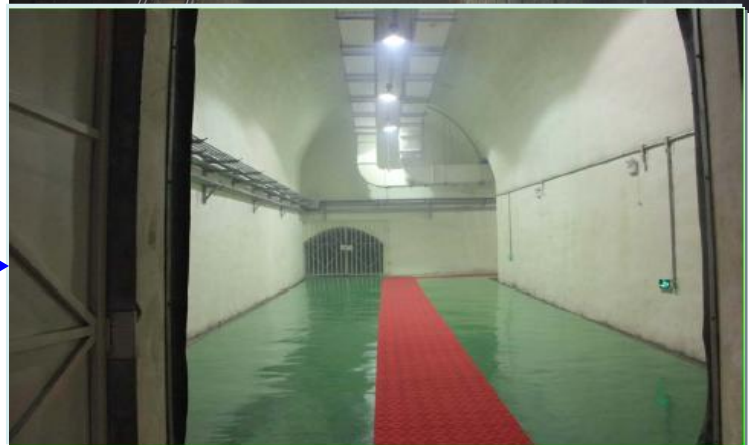
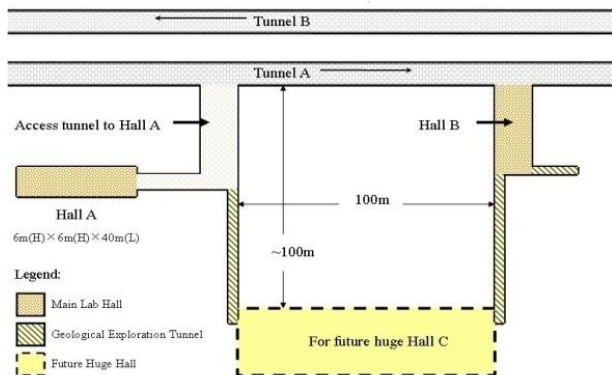
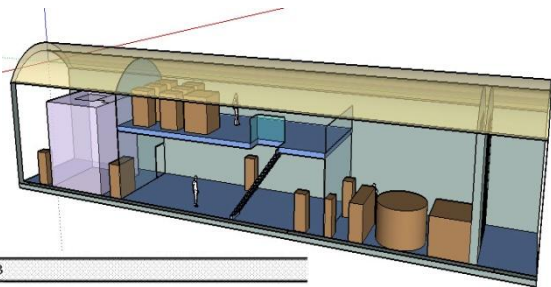
Mt. Jin-Ping Tunnel (锦屏山隧道)

Status & plans in CJPL

- ⊙ 6X6X40 m Lab built (c/o THU)
: completed excavation
- ⊙ Phase-I (2010.9-2011.3)
 - 20g ULE-HPGe detector @ CDUL
 - Shielding system construction
 - HPGe detector for radioactive measurement
 - Radon monitor system

First Step of construction: 6*6*40 m Lab.

Hall A Layout



Status and Plans

- Competitive limits at *WIMP-mass* $< 10 \text{ GeV}$ already obtained with **Sub-keV Ge prototype** at a shallow site, for both spin-independent and spin-dependent couplings.
- Further optimizations of experimental procedures, **shielding configurations**, and **pulse shape analysis** software, plus studies of **systematic effects**
- Studies on **background understanding, discrimination of surface and bulk events** at *sub-keV* range.
- **Sub-keV Ge quenching factor measurement & Ions Channeling effect** at *CIAE* neutron facility in 2010
- **Plan** : move to *CJPL* (>2 km rock) soon
- **Goals** : open new detection channel and detector window for neutrino and dark matter physics